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ABSTRACT

The purpose of this paper is to assist those in education, government, and industry who are responsible for managing vocational and technical training in their decisions about what programs should be initiated to accommodate the growing use of robots. Section 1 describes robot characteristics (type of drive, method of teaching, lifting capacity, shape, type of motion or path, and sensory capabilities). Robot systems, computer-aided design and manufacturing, and flexible manufacturing are also defined. In section 2 the practicalities of robot applications are discussed in terms of payback periods and constraints on robot usage. The third section attempts to assess what may happen to robotics over the next few years, including changes in: (1) performance characteristics of robots (sensory perception and control), (2) their degree of use, (3) producers, and (4) impacts of robots on employment. The last major section makes recommendations for robotics education at the vocational and two-year college levels. Recommendations include no robotics training in secondary vocational schools and teaching of robotics at the two-year college level as part of an integrated approach to automation, with electronics as the core curriculum. Recommendations are also made to industrial managers considering robotics and government manpower agencies considering retraining programs. (YLB)

Robots, Jobs, and Education

STATE-OF-THE-ART PAPERS

OFFICE FOR RESEARCH IN HIGH TECHNOLOGY EDUCATION
The University of Tennessee   College of Education

Robots, Jobs, and Education

by

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ROBOTS, JOBS, AND EDUCATION

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FOREWORD

The Office for Research in High Technology Education at the University of Tennessee, Knoxville, is conducting a program of work on high technology and its implications for education. Funded by the U.S. Department of Education's Office of Vocational and Adult Education, the program addresses the skill requirements and social implications of a technology-oriented society. Issues concerning computer literacy and computer applications are a focus of the program. The balance between the liberal arts and technological skills and the complementary roles they play in enabling people to function in and derive satisfaction from today's high-technology era are also addressed. The program's efforts are targeted at secondary schools, two-year post-secondary institutions, community colleges, universities, industrial training personnel, and other education and training groups.

The program consists of three major components:

At Home In the Office Study - At Home In the Office is an experiment that has placed office workers and equipment in the workers' homes to determine (1) what types of office work can effectively be done at home and (2) the advantages and disadvantages of home work stations. The implications for educators, employers, and employees will be significant, as work at home offers a possible avenue of employment for people living in rural areas, parents of pre-school children, handicapped individuals, and others.

COMTASK Database - COMTASK is a model of a computerized task inventory for high-technology occupations. The outcomes of the COMTASK system include a sampling of task analyses, the demonstration of how these task analyses can be rapidly updated, a manual for conducting task analyses to provide data for the system, and a guide to using the system.

State-of-the-Art Papers - A series of nine papers is being developed to address high technology and economic issues that are of major concern to education. Nine working titles have been selected:

- The Changing Business Environment: Implications for Vocational Curricula
- Computer Literacy in Vocational Education: Perspectives and Directions
- Computer Software for Vocational Education: Development and Evaluation
- Educating for the Future: The Effects of Some Recent Legislation on Secondary Vocational Education
- The Electronic Cottage
- High Technology in Rural Settings
- (Re)Training Adults for New Office and Business Technologies
- Robots, Jobs, and Education
- Work in a World of High Technology: Problems and Prospects for Disadvantaged Workers

Abstract

Publicity about industrial robots has created a flurry of activity in education. Over 200 two-year colleges now offer associate degrees in robotics or related fields.

The authors believe that, at the two-year college level, robotics should be taught as part of an integrated approach to automation, with electronics as the core curriculum. Being able to plan and coordinate the application of robots to other machines is a critical skill in robotics. This requires some ability in mechanics, hydraulics, and pneumatics, but especially in electronics -- the central nervous system of machine communication. Competence in electronics is thus essential to robotics.

However, it appears that having a knowledge of robotics alone will not be sufficient for success in the job market, at least in the near future. As this paper points out, there just aren't enough robots. Thus, the authors maintain that students interested in robotics should master the basics of electronics so that they can find jobs even if they never see a robot after leaving school.

About the Authors

Oliver Benton, an industrialist with over twenty years' experience in production management, joined the Chattanooga State Technical Community College in 1981 as the first director of its Center for Productivity, Innovation, and Technology. The Center is a cooperative effort among the college, the Tennessee Valley Authority, and local industry to provide training in such state-of-the-art technology as robotics, computer-aided design, computer-aided manufacturing, and automated information management.

Charles Branch is an educator and administrator with a twenty-year record of accomplishments. He designed and initiated the Center for Productivity, Innovation, and Technology in an effort to assist local industries to retool, modernize, and expand into high-technology fields.

About the Editors

This paper has been prepared as part of a series of state-of-the-art papers edited by Lillian A. Clinard, an associate director of The University of Tennessee's Energy, Environment, and Resources Center (EERC), and Mary R. English, a research associate at EERC. The editors, who have been on assignment to the Office for Research in High Technology Education, were responsible for selecting the series' authors, reviewing and coordinating external reviews of the papers, and preparing the papers for release.

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INTRODUCTION

The Robots Are Coming . . . Aren't They?

Invite a newspaper reporter to do a story on an automated machinery cell and you will get a brief telephone interview. Invite the same reporter to do a story on three robots making parts without people and you will get front-page color photographs, a mixed editorial, and, three days later, several letters to the editor denouncing you for putting Americans out of work! Such is the emotional impact of robots. They make good newspaper copy.

Robots are being discussed from every possible perspective -- from sophisticated industrial applications to fanciful humanoids performing our routine household tasks. All of this publicity has served a useful purpose. It has awakened the American public to needed and possible changes in manufacturing companies. Robots are interesting, even to nonmanufacturing people, whereas manufacturing machinery is not.

The publicity has caused bright young people to take a fresh look at careers in manufacturing. Manufacturing is now part of most curricula for master's degrees in business administration. Television programs about Japan's "unmanned" factories have challenged U.S. corporate executives and federal government policymakers to improve our productivity. Union leaders openly support the use of robots as a necessity.

So far, so good. But there is a danger that this publicity could lead to overreaction in education and in government policy. Even in the hard-nosed world of manufacturing, it is entirely possible to jump on the robot

bandwagon because robots are so modern. In fact, however, as a result of poor planning by management there are already robots gathering dust in several plants around the country.

For those American companies which produce or sell robots, 1983 was a disappointing year. According to the New York Times (March 4, 1984), industry sales are far below expectations, and only one American company, Prab Inc., made money in robotics in 1983. Some companies, such as Copperweld, have abandoned the robot business altogether. Others, such as Unimate -- the founding company in robotics -- have not made money and are being acquired by larger companies. Robot sales personnel report slow sales and meager commissions. Since 1963, when robots were introduced in the United States, the U.S. robot population has risen to only 6,500 (New York Times, March 4, 1984).

Are we saying that the robots are not coming? Are they just some kind of industrial hula hoop? If so, why have General Electric, Westinghouse, and IBM set up robot systems divisions to sell robots? Surely they see something substantial in the future. The answer is not simple. Robots are indeed coming, but they are coming slowly. They are only in the crawling stage, with dim eyesight, limited touch, and virtually no hearing, and they are not coming independently. To function effectively, they must be a member of an automated system of machines.

Objectives and Scope of this Paper

This paper is directed primarily toward those in education, government, and industry who are responsible for managing vocational and

technical training. The paper's purpose is to assist those managers in their decisions about what programs, if any, should be initiated to accommodate the growing use of robots.

Although this is not intended as a technical paper, we will discuss in some detail the nature of robots, where they are now, how they are used, and what is likely to come up next.* It is important for managers concerned with job training to understand the capabilities and limitations of today's robots. It is also important for them to recognize that today's robots are in an embryonic stage of development -- the robots of 1990 will look like today's robots, but their capabilities will be far, far greater because of improved sensory devices and controls.

Thus, educators and others concerned with jobs and training must understand the pace at which robots are coming, and they must understand what industrial jobs these robots will do. But most important of all, they must understand the people and training needed (and not needed) to take full advantage of the robots.

Most educators and government manpower specialists base their reactions to robots on available forecasts of robot usage and worker displacement, but these can vary widely. (E.g., depending on the source, forecasts of the number of American workers to be displaced by robots in the next ten years vary from 50,000 to 1,500,000.) Accordingly, in this

*We have used Industrial Robots - A Delphi Forecast of Markets and Technology by Donald N. Smith and Richard C. Wilson (Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan, 1982) as a major source of statistics for this paper because their survey was based on detailed information obtained from companies that were already familiar with robots and had them in actual use. However, this Delphi forecast deals primarily with the physical aspects of robots, whereas our paper concentrates on their implications for employment and training.

paper we will present a variety of forecasts by industry and application. We will then attempt to make realistic assessments of conflicting forecasts -- assessments which we hope will be useful to those who must plan for effective training.

In the last major section, we will recommend several possible courses of action for educators and manpower specialists in government and industry. These recommendations reflect our combined experience of 20 years in technical education, including 3 years in robotics; over 20 years in metal-working manufacturing management; and several years as volunteer chair of the local Private Industry Council. Since our technical education experience has been at the vocational and two-year-college level, the recommendations will be limited to those areas. Furthermore, the scope of these recommendations will be limited to robotics in the foreseeable future, from 1984 to 1990. And finally, no attempt will be made to address the long-term decline in manufacturing jobs -- a decline caused by many factors, of which robotics is only one.

WHAT IS A ROBOT?

Robot Characteristics

The Society of Manufacturing Engineers has identified two common, but quite different, definitions of robots:

- In Japan, a robot is usually defined as "a computer-controlled device for moving material or performing work."
- In the United States, a robot is usually defined as "a computer-controlled, reprogrammable, multi-function manipulator capable of varied programmed motions."

The word "reprogrammable" is the key difference. Japan's robot statistics include many production devices that would not be labeled "robots" in the United States. Using the Japanese definition, Japan has from 10 to 15 times as many robots as the United States. Using the U.S. definition, Japan's usage is more like 3 times as great as that in the United States.

But neither of these broad definitions fully describes a robot, since many robots are designed with specific applications in mind. (For example, jointed-arm robots -- which account for over 50 percent of all robots sold in the United States -- were originally designed for arc welding, although most are not used now for that purpose.) To understand a robot, we thus must look at its type of drive, method of "teaching," lifting capacity, number of axes or "joints," type of motion or path, sensory capabilities, and primary intended use.

Type of drive. For training purposes, this is one of the most important aspects of a complete robot definition. A person who selects, installs, and maintains robot systems must be trained in the type of drive

demanded by the particular application. There are three popular types of drives:

- Pneumatic. Compressed-air drives are used on comparatively simple low-cost robots. The robot's electronic controller activates solenoids and air logic devices which control the air. Feedback is accomplished by signals from limit switches and air logic devices. These are popularly called "pick and place" robots.

- Electric. This is becoming the most popular type of drive, since it is flexible and easily controlled. At one time, electric robots were considered primarily for light-weight jobs, lifting up to about 100 pounds, but recently, electric robots have been designed for loads of up to 1,000 pounds.

  Most industrial robots use servo motors, which are capable of an infinite number of controlled positions. Alternate-current (AC) servos are replacing direct-current (DC) servos, because AC servos are smaller and require less maintenance. Educational robots frequently use lower cost "stepper motors" which have a fixed number of controllable positions.

- Hydraulic. Hydraulic drives, which involve oil pumped at high pressure through positioning devices, were used for the early Unimate robots. Until recently, hydraulic drives were preferred for robots carrying loads of 100 pounds or more. They are still used for very large loads and for paint-spraying operations where electric sparks are undesirable. However, the hydraulic drive is on the decline because it is expensive, requires high maintenance, and inevitably creates messy oil leaks on the factory floor.

Regardless of the robot's type of drive, most robot grippers are pneumatically activated. Thus, some pneumatics training is necessary in any course of robotics study.

Method of teaching. Notice that we use "teaching" rather than "programming." ("Programming" is something else; we will get to it below.) Basically, robot motions are taught by positioning the robot and then pushing the "teach" button. This causes the robot to remember that position. The robot can be moved to the desired position in several ways.

The most popular involves a "teach pendant" -- a hand-held box connected by cable to the robot control with buttons for various motions -- plus a "teach button" to record each positon.

Less popular, but nearly always used in paint-spraying applications, is the lead-through method. Here, the end of the robot is simply grasped and moved through the desired motion path. The robot must be designed for this type of teaching.

Neither of the above methods requires any computer training whatsoever of the robot operator. According to the Nissan Motors training department in Smyrna, Tennessee, the typical industrial worker can, with about one week's training, learn to teach a robot.

Table 1 shows present and predicted methods of teaching robots.

Table 1. Present and Predicted Percentage of Robots Sold, by "Teaching" Method

	1981	1985	1990
Leading from point to point	24	23	22
Pendant-control teach mode	58	47	33
Off-line programming language	6	18	28
Hybrid of the above[a]	12	12	17

[a]Any combination.

Source: From Industrial Robots: A Delphi Forecast of Markets and Technology (p. 36) by D. N. Smith and R. C. Wilson, 1982, Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan.

"Off-line programming" in the above table refers to computer

programming at a station not connected to the robot, with the program to be fed later to the robot. Certain new robots, particularly the IBM assembly robots, allow off-line programming using a personal computer. (The IBM robot can also be taught with a teach pendant.) This program then "teaches" the robot its motions. This type of off-line programming would definitely require computer training for the operator.

In the authors' opinions, however, off-line programming will not achieve anything close to the 18 percent predicted for 1985 in Table 1, since this type of teaching requires that a robot go with great precision to the desired position on its own, the first time. Most of the robots available in 1984 will not do this accurately enough. They must first be directed to the desired position using a teach pendant or the lead-through method. They will then repeat that point very closely.

Off-line programming has one obvious advantage over the other teaching methods (including the hybrids): a new series of motions can be developed without taking the robot out of production. Also, in the case of the IBM assembly robot and perhaps other robots, teaching by off-line programming allows a more precise location of each point in the series of moves. For this reason, off-line programming may become the dominant method for precision electronic assembly using robots. Since IBM is a leader in computers as well as robotic assembly in its own plants, it is reasonable to assume that IBM would be a leader in marketing this type of robot.

Weight-lifting capacity. One of the most important performance characteristics by which a robot may be defined is weight-lifting capacity. There are small pneumatic and electric robots designed to lift

only a few ounces. Seiko makes and uses such robots to assemble watches. At the other extreme, Cincinnati-Milacron's T-3 hydraulic robots are rated at several hundred pounds of lifting capacity. Robot lifting capacities are normally calculated with the robot arm fully extended. An hydraulic robot rated at a 300-pound capacity is reported to have lifted -- with its arm close to its body -- a lathe weighing 8,000 pounds when the lathe clutch refused to release the workpiece!.

Roughly 50 percent of the robots in use handle parts weighing less than 25 pounds. Only 6 percent handle parts weighing 100 pounds or more. This situation is not expected to change greatly over the next few years (Smith & Wilson, p. 16). Table 2 shows the breakdown by industry of the average weights robots are expected to handle, now and over the next few years.

Table 2. Present and Predicted Average Weight of Parts Robots Handle, by Industry (in lbs.)

	1980	1985	1990
All Industry	20	20	25
Automotive	25	20	20
Casting/foundry	40	50	50
Heavy manufacturing	60	70	100
Light manufacturing	10	10	10
Electrical/electronic	3	3	2
Aerospace	10	15	15

Source: From Industrial Robots: A Delphi Forecast of Markets and Technology (p. 16) by D. N. Smith and R. C. Wilson, 1982, Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan.

Robot prices in 1984 vary from about $10,000 to $125,000, but these prices are not directly related to the robot's weight-lifting capacity. A small, sophisticated 5-axis jointed-arm robot with a 6-pound lifting capacity may cost $38,000. Its big brother capable of lifting 22 pounds may cost $48,000 -- a weight increase of 266 percent with a price increase of only 21 percent. Both robots are likely to use the same control computer and software, and that is one of the reasons that their costs are not proportional to their weight-lifting capacities. A sophisticated control costs the same, whether it is connected to a 5-pound-capacity robot or a 50-pound-capacity robot.

Shape. Robots come in all sorts of shapes, or configurations. The most common is probably the jointed-arm robot, which typically has 5 axes or joints, including base rotation. These robots are generally the most flexible shapes. They are sometimes known as general-purpose robots and can perform just about any task written within their weight-lifting and reach capacities. The General Electric Model P-50 is a good example of a 22-pound-capacity version of this type of robot.

Another popular shape is the cylindrical coordinate robot. This rotates around a vertical post and generally has a horizontal arm with a wrist at the end. The arm can move up and down on the post but does not have a shoulder or elbow joint. This type of robot provides an economical method for loading machines or transferring material. The General Motors/Fanuc (GMF) M1A is a good example of a 100-pound-capacity robot of this type.

A small combination jointed-arm and cylindrical shape is becoming

popular for small-parts assembly. This type of robot mounts on a table and swings a horizontal arm with an elbow. Although small, it has very sophisticated controls. The General Electric A-4 and IBM 7535 robots are typical of this shape. They generally have 4 axes.

Type of motion or path. This characteristic is difficult to describe in detail without a series of drawings which would go beyond the scope of this paper. It will suffice to say that some robots are capable of much more sophisticated path control than others, because of differences in their control software. You can't tell this just by looking at the robot, but it can be an important distinction. In arc welding, for example, it is critical that the robot follow a known path between points A and B. However, when a robot is transferring material from one conveyor to another, the exact path taken may be unimportant, just so long as the robot picks the part up properly at A and sets it down properly at B.

Special-purpose robots. Robots are now being designed for specific applications. Perhaps the most novel robots are those in use in Australia which were developed for shearing wool off live sheep. The robot is programmed to cut the wool within a certain distance of the sheep's hide, and we're told that the sheep is given a mild electric shock to persuade it to lie still. The robot has a series of sensors or feelers which allow it to follow the contours of each particular sheep. The sensors also detect the movement caused by the sheep's breathing and adjust the robot's motions accordingly. The result is a closer cut without injuring the animal.

For 30 years quasi-robots have been used to handle radioactive material at the Oak Ridge National Laboratory (ORNL) in Oak Ridge,

Tennessee. These are not true robots because they are controlled by humans manipulating remote mechanical linkages, but now robots are being developed which can operate on their own in the ORNL labs.

At a recent robotics demonstration in Gatlinburg, Tennessee, the ODEX II, made by Odetics, Inc. of Anaheim, California, was the hit of the show. This 370-pound daddy longlegs can walk, climb into the bed of a pickup truck, and lift nearly six times its own weight. It is still experimental but shows promise for many applications. For example, like the ORNL robots, it could be used to operate independently in a hostile environment.

Robot grippers, or hands. Robots are made without hands. The hand, usually referred to as a gripper, must be designed for the job the robot is going to do. Different hands allow the robot to do different jobs, but not all different jobs require different hands.

For example, on a recent visit to a robot manufacturer's application lab, we observed a robot using the same gripper for two related but quite different types of customer jobs. The robot first picked up a pneumatic applicator for silicon sealant and sealed the joint between the floor and firewall of an auto body assembly. The same robot, with the same gripper, then picked up a pneumatic applicator for cake icing and decorated the mouths, ears, and eyes of chocolate Easter bunnies passing on a conveyor.

Grippers are usually pneumatically operated because air is cheap, light-weight, and easy to control. Hydraulic grippers are occasionally used, especially when a heavy gripping force is needed, and small electric grippers are also available.

The weight of the gripper must be counted against the lifting capacity of the robot. In other words, a robot capable of lifting 22 pounds can only handle 15 pounds if its gripper weighs 7 pounds.

Gripper design and procurement is a problem facing the robot user, for, strangely enough, most robot manufacturers do not make grippers. Some sources are available, however. General Motors/Fanuc and G.C.A. Corporation each sell a line of stock grippers, and other robot manufacturers will, for a fee, design the gripper for a customer application and have it made in a local machine shop. In addition, several small companies specialize in making lines of stock grippers, usually small pneumatic devices with very stubby "fingers." The fingers are tapped so that "finger extensions" made by the customer to fit the work to be handled can be easily attached.

As more robots are sold, the larger manufacturers such as GMF, Cincinnati-Milacron, , and General Electric are offering turnkey robot systems designed to the customer's job. This type of system includes the robot, all auxiliary equipment, and the gripper. In complex applications, it may include several robots, conveyors, and controls, together with complete installation.

Robot Systems, CAD/CAM, and Flexible Manufacturing

These terms are often used in an overlapping way and need to be more precisely defined for the purposes of this paper.

Robot systems. Almost any manufacturing application of a robot is a system, because the robot requires devices to feed the parts in, orient

them, and feed them out. However, "robot system" usually refers to a production line with many robots and support devices, whereas small systems with one or two robots are called cells. In the typical robot system, the cost of the robot amounts to about 40 percent of the system's total cost. Thus, in an arc-welding cell, the robot may cost $45,000 with the total cell costing $125,000.

CAD/CAM. These two acronyms are used together so often that many people are surprised to find that the terms are generally unrelated. In actual practice, CAD refers to computer-aided design; a device used in design engineering departments; CAM refers to computer-aided manufacturing, which can mean almost anything. When used together, CAD/CAM means the electronic connection between design devices and production machines, both controlled by computers.

By cutting engineering and manufacturing lead times and by improving acccuracy and quality, CAD/CAM systems could have enormous implications for manufacturing, but because of their cost and complexity they are not being used extensively. Very little CAD/CAM is going on in American industry now, nor is much expected in the near future. Table 3 illustrates this point, and Table 4 lists some of the obstacles perceived by American manufacturers to adopting CAD/CAM systems.

Flexible manufacturing systems. These should usually be called flexible machining lines because they most frequently consist of several general-purpose metal-cutting machines with a few robots feeding them from conveyors. One robot and one machine tool might be a simple flexible machining cell. A more complex system might involve the machine tools,

Table 3. Predicted Percentages of CAD/CAM-interfaced Robots Sold, by application

	1985	1990
Assembly	5	15
Inspection	10	20
Welding	5	10
Painting	5	10
Grinding	5	10
Routing	10	15
Machine loading	5	10
Parts Transfer	5	10

Source: From Industrial Robots: A Delphi Forecast of Markets and Technology (p. 64) by D. N. Smith and R. C. Wilson, 1982, Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan.

Table 4. Largest Obstacle to Implementation of CAD/CAM-interfaced Robots

Obstacle	% Responses[a]
Economic justification (cost, profitability, productivity)	17
Technical personnel requirements	13
Software/programming	12
Data base development and maintenance	8
Interfacing with existing equipment	7
Employee acceptance	5
Management commitment	5
Lack of expertise with robots	4
Lack of industry standards	4
Maintenance requirements	3
Better sensors and feedback required	3
Shortage of computer power	1
Other mechanical problems	13
Other management problems	6
	100

[a]Percentage of responses in Delphi Forecast Survey.

Source: From Industrial Robots: A Delphi Forecast of Markets and Technology (p. 65) by D. N. Smith and R. C. Wilson, 1982, Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan.

robots, a conveyor or parts mover of some sort, and a host computer to coordinate everything. Acccording to Smith and Wilson's Delphi forecast (p. 46), in 1985, of all the robots sold, 80 percent will be sold as individual units, with 20 percent as components of flexible manufacturing systems; by 1990, this proportion is expected to become 60 percent and 40 percent, respectively.

PRACTICALITIES OF ROBOT APPLICATIONS

Payback Periods

Much has been written about robots improving production quality or relieving humans from boring or hazardous work. But in 1984, robot salesmen report that cost reduction is the only incentive to which prospective robot buyers are responding. A former employee of John Deere Company says that Deere's primary objective in its initial robot application was to eliminate hot, dirty, dangerous, and otherwise unpleasant jobs, and to his knowledge the company did not intend to lay anyone off because of the robot installation. Upon further discussion, however, it became apparent that the productivity of people on these jobs had been very low; with robots, it would be very high. So we're back to economics.

The authors have firsthand knowledge of a typical robot application near Chattanooga State Technical Community College. One robot will replace two operators per shift loading two presses. The robot costs about $45,000 and the associated accessories and feed devices cost about $35,000, for a total of $80,000. Assuming the robot will replace four people, the payback period is roughly one and one-quarter years. This company is growing, and no employees will lose their jobs. The robot will help the company meet Japanese competition.

Companies installing robots look for a payback period of two years or less. This is an unusually short payback expectation for a large capital investment, but it is the one normally associated with tools, dies, and

hard automation, all of which may become obsolete within two years. According to Smith and Wilson (p. 38), in 1981, the automotive, casting and foundry, heavy manufacturing, light manufacturing, electrical and electonic, and aerospace industries all sought average payback periods of from two to three years, and these averages were not expected to change substantially in the near future.

The largest item in calculating a robot's payback period is direct labor savings (see Table 5). This is usually followed by quality improvement as measured by reject reduction. Arc-welding applications in particular yield unusually apparent increases in quality: a robot can do a far more consistent job. For this reason, arc welding has been the single largest robotics application.

Table 5. Present and Predicted Percentage of Direct Labor Productivity Gains from Robot Applications

Application	1980	1985	1990
Inspection	20	30	40
Assembly	20	25	35
Manufacturing Processes	20	20	30
Continuous Path Purposes	25	30	35
Pick-and-Place Purposes	25	25	40

Source: From Industrial Robots: A Delphi Forecast of Markets and Technology (p. 41) by D. N. Smith and R. C. Wilson, 1982, Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan.

Regardless of the application, robots are more likely to be used where employee wages are high or rising rapidly. As robots become more versatile, their costs per hour of operation will go down, whereas wages

will probably continue to increase.

It is very difficult to generalize about the hourly cost of a robot, but the current estimate is around $8. This is roughly based on a $100,000 robot cell working 3,600 hours a year for three and one-half years. As production wages in applications appropriate to robots exceed $8 per hour, robots will be considered.

Constraints on Robot Usage

Technical barriers. . . . Would you hire this person?

> Position wanted:
>
> Severely handicapped worker available. One arm, two fingers. Legally blind, totally deaf, can communicate by signals only. Unable to walk. Limited sense of feeling in fingers. Slow but steady worker. Will work any and all shifts. No objections to hot or dirty work. Will follow instructions to the letter. Does not drink, smoke, or chew. Will be on the job 98 percent of the time. No coffee or restroom breaks.

There you have a personification of today's typical robot. In spite of the tremendous technical advances in robotics over the past ten years, robots are difficult to apply to most factory operations. The authors have evaluated many potential robot applications in plants of all types. In most plants, the central difficulty lies in presenting manufacturing parts to the robot in a precise, organized fashion. Most robots cannot reach into a box of loose, random parts and pick one out. Parts must be presented with a feeder device so that the part is in the proper location each time. In many cases, when the cost of the feeder device is added to the robot's cost, it becomes cheaper or easier to continue with a human operation.

Thus, perhaps the single greatest technical barrier to robot usage is the robot's blindness. Artificial vision systems for robots hold great promise but are in limited use. General Motors recently bought part-interest in two firms which manufacture vision systems; General Electric markets a form of its Optimation vision system for bin-picking operations; and Machine Intelligence Corporation has a joint marketing effort with Unimate, coupling Machine Intelligence's vision system with the Unimate Prima robot. All of these systems use a solid-state television camera with the image processed through a computer to the robot. However, the vision systems themselves are in an early stage of development, and most robots cannot yet make use of the computerized television image.

Other technical improvements are also needed, particularly in robot accuracy, weight-lifting capacity, speed, off-line programming capability, and tactile sensing.

High interest rates. High interest rates impede capital investment. It is much more difficult to justify the cost of a robot when interest rates are 12 1/2 percent than when they are 5 1/2 percent. (At the time this paper was written, in August, 1984, the prime lending rate in the United States was 12 1/2 percent; in Japan, 5 1/2 percent.) With a typical robot costing from $45,000 to $80,000 and a robot system costing perhaps $3 million, the cost of money is significant.

Slow growth and erratic business cycles. Even if a robot will pay for itself in three years -- a 33 percent return on investment -- three years is a long time in the present U.S. business cycle. The types of companies using robots, mostly metal-working, rarely enjoy three consecutive years of

good, steady business. Many managers simply are afraid to make long-term investments. This is why they look for a payback period of no more than two years. They see, or think they can see, two years ahead. But not much more.

Lack of trained people. Manufacturing doesn't have an abundance of experienced and technically trained managers -- since the early 1950s, it has failed to attract enough of the brightest, most aggressive young people. By and large (although not in the very largest firms such as General Electric, IBM, and the aerospace companies), today's factory-floor managers grew up in the shop. They thus have a wealth of shop experience, but they are not technically trained and have a strong bias toward the status quo. The problem of technical training for managers is being vigorously addressed by the Society of Manufacturing Engineers and its subsidiary, Robotics International.

Poor implementation. If a company's first robot application is not successful, the company is unlikely to install more robots until there is a change in managers. Why should a robot application fail?

- Poor choice of application. Perhaps the operation to which it was applied is just too complex for today's robots. This reflects poor management judgment.

- Inability to provide robot with consistently high-quality parts. Humans adapt; robots don't.

- Operation obsolescence. Operation suddenly becomes obsolete due to a canceled order or a change in marketing.

- Poor worker training or poor communication with workers. People make robots work. Some of those people are the operators performing work which is fed to or taken away from the robot. If workers want to make a robot fail, they can. Workers should be on the team that performs the feasibility study before the robot application is adopted, because teamwork -- and worker acceptance -- will be important to the robot's success.

ROBOTS OF TOMORROW

> Accurate predictions are difficult to make, especially when they concern the future.

There is wisdom in this bit of nonsense. Predicting the future of robotics in a way that can be useful is probably impossible. In the mid-1950s, one of the authors was involved in predicting computer usage. All sorts of studies were done and projections made. But the invention of the transistor, completely unforeseen by a layperson, made all these predictions obsolete. The same sort of thing may occur in robotics. Nevertheless, this section will attempt to assess what may happen to robotics over the next few years -- what changes can be expected in the robots themselves, in their degree of use, in the companies producing and selling robots, and in their impacts on employment.

Performance Characteristics

The laws of physics regarding leverage and weight are not likely to change, so most of the robots of 1990 will look similar to today's robots. But, as suggested below, the robots' capabilities -- particularly their sensory perception and control -- may vastly increase over the next six years.

Vision. Tomorrow's robot vision systems will be three dimensional. When coupled with an improved robot control, the vision system could direct the robot hand to new spatial points defined by three coordinates. This, in the authors' opinions, will lead to the largest single robotics improvement. Robots could then see and grasp parts even if they were not

presented in an orderly fashion, enabling robots to be used in hundreds of thousands of now infeasible applications.

When will this happen? It depends on unpredictable technical breakthroughs, but it probably will happen. Many large companies and universities are working on it. Among the companies, General Electric is a leader. Among the universities, Stanford and Carnegie Mellon.

Language. As robots develop better sensory perception, their language capability will also improve. It may soon be possible to give a single instruction which tells the robot to "move from point A to point B but circle above and around any object between those two points."

IBM and Unimation already have off-line programming languages. As other robots become more sophisticated, they will be offered with languages for off-line programming.

Touch. How can a robot determine when an object is about to slip from its grasp? This sensitivity is needed to hold a delicate object tight enough but not too tight. Human fingers can detect and prevent a slippage before it occurs. Robots may be able to soon. Improved tactile sensing will be necessary if robots are to perform the subtle work required on delicate or soft objects. For example, the robot finger should be able to detect the shape of an object by touching it, just as a human finger can. A human finger readily distinguishes a knife's cutting edge from its back edge. A robot finger does not.

Proximity sensing. The ability to sense an impending collision is important. Robots could have this ability now if their vision systems were improved and if obstructions were lighted properly. But something better

is on the way. Proximity sensors, already available, will be improved and fitted onto every robot. When an object is in the robot's path, the sensor will stop the robot or direct it to a preprogrammed alternate route.

Self-locomotion. This can be the ultimate application of all the other improvements. With adequate sensors and a sophisticated control, there is no reason a robot could not roam the factory floor, performing all sorts of useful tasks. When the shift ended, the robot would retire for the evening to the battery charging room, hooking itself up to the charger and setting the charging time depending on the condition of its battery.

Robot Usage

The U.S. robot population rose from 6,300 in December, 1982 to about 9,500 in early 1984. (New York Times, March 4, 1984). However, the U.S. Department of Commerce predicted that sales of robots (domestic or foreign-made) in the United States would reach $270 million in 1983, while the actual total reached only $137 million -- roughly 50 percent of the forecast. And this was in a year when business conditions were good and interest rates relatively low compared with 1982 or 1984. Thus, all predictions regarding robots must be treated warily.

Forecasts of total robot usage in the United States by 1990 vary from a low of 30,000 to a high of 300,000. In dollar volume, the figure most frequently quoted is $2 billion. The forecast of robot usage which we have chosen as being most probable is shown in Table 6. Most of the robots forecasted will be used in metal-working companies. In fact, most of the forecasts which we have reviewed (e.g., the Delphi forecast, the Upjohn

Institute study cited further below, and virtually all vendors' forecasts) show the automobile industry using 20-25 percent of the total U.S. robot population. However, as illustrated in Table 7, the use of robots by industries in the "other" category is expected to grow rapidly.

Robot Producers

Most of the robots offered for sale in the United States are made in Japan. The list below is not intended to be all-inclusive but merely illustrates the way the market is supplied. New manufacturers are continually entering the market, and others are changing affiliations.

Brand Name	Manufacturer and Country of Origin
Asea	Asea -- Sweden
Bendix	Yaskawa -- Japan
Cincinnati-Milacron	Cincinnati-Milacron -- U.S.
General Motors/Fanuc	Fanuc -- Japan
Hobart	Yaskawa -- Japan
IBM	Sanko -- Japan
Prob	Prob -- U.S.
Unimation	Westinghouse -- U.S.
De Vilbiss	Thermwood -- U.S.

At the 1984 annual robot show (Robots VIII, held in Detroit), Cincinnati-Milacron advertised itself as number one in U.S. robot sales. However, many observers believe that GMF is the leading U.S. seller. Unimation, now a division of Westinghouse, lost its lead when the market shifted from hydraulic to electric robots. The Wall Street Journal of

Table 6. Forecast of U.S. Robot Population, by Application, 1990

Application	Autos Range of Estimate Low	Autos Range of Estimate High	All Other Manufacturing Range of Estimate Low	All Other Manufacturing Range of Estimate High	Total Range of Estimate Low	Total Range of Estimate High
Welding	3,200 (21.3%)	4,100 (16.4%)	5,500 (15.7%)	10,000 (13.3%)	8,700 (17.4%)	14,000 (14.1%)
Assembly	4,200 (28.0%)	8,800 (35.2%)	5,000 (14.3%)	15,000 (20.0%)	9,200 (18.4%)	23,800 (23.8%)
Painting	1,800 (12.0%)	2,500 (10.0%)	3,200 (9.1%)	5,500 (7.3%)	5,000 (10.0%)	8,000 (8.0%)
Machine loading	5,000 (33.3%)	8,000 (32.0%)	17,500 (50.0%)	34,000 (46.0%)	22,000 (45.0%)	42,000 (42.0%)
Other	800 (5.3%)	1,600 (6.4%)	3,800 (10.9%)	10,500 (14.0%)	4,600 (9.2%)	12,000 (12.1%)
Total	15,000	25,000	35,000	75,000	50,000	100,000

Source: From Human Resource Implications of Robotics (p. 50) by H. A. Hunt and T. L. Hunt, 1983, Kalamazoo, MI: The W. E. Upjohn Institute for Employment Research.

Table 7. Present and Predicted Percent of Total Robot Shipments, by Industry

Industry	1979	1980	1981	1982	1983	1984	1985
Automotive	17.8	20.0	22.2	23.3	23.3	23.3	22.5
Casting/foundry	21.3	19.4	20.0	20.0	14.0	13.3	11.3
Heavy manufacturing	9.9	9.7	8.9	8.3	8.1	7.5	6.3
Light manufacturing	36.6	33.3	33.3	33.3	27.9	31.7	25.0
Electrical/electronic	11.1	11.1	9.8	11.7	9.3	10.0	8.1
Aerospace	0.9	1.1	1.3	1.7	2.1	2.1	2.0
Other	2.9	5.4	4.5	1.7	15.3	12.1	24.8
All Industry	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: From Industrial Robots: A Delphi Forecast of Markets and Technology (p. 51) by D. N. Smith and R. C. Wilson, 1982, Ann Arbor, MI: Society of Manufacturing Engineers/University of Michigan.

June 14, 1984, reported that Unimation had laid-off 40 percent of its workforce.

Vern Estes of General Electric robotics, winner of the 1983 Engleburger Award in robotics, acknowledges that the huge entry cost in the robotics business will make it difficult for many companies to survive. Some, such as Copperweld, have already dropped out. The authors believe that the business will settle itself into a dual market pattern: (1) large companies such as GMF, General Electric, and Cincinnati-Milacron will be the market leaders in general applications; and (2) there will be a number of strong companies carving out a niche in specialty applications — for example, Seiko in precision assembly and Thermwood in paint spraying.

But regardless of the market lead in the United States, the manufacturing lead is likely to remain in Japan. Of the U.S. manufacturers, Cincinnati-Milacron appears to be the leader. To our knowledge, they make all of the robots they sell.

Impacts of Robots on Employment

Whole books have been written on this subject. Unions have forecast a loss of membership. School and college administrators have forecast new career training needs. College professors find a ready market for their long-term projections. Trade associations such as the Society of Manufacturing Engineers hire consultants to determine job trends. Government manpower specialists, the U.S. Department of Labor, and the U.S. Department of Education hire technical specialists to analyze the employment problem. In fact, robots have created a sizable number of jobs

for people who just write about the impact of robots.

This paper will not list all of the published opinions on the employment impact of robotics. Instead, we want to present our own opinions about the impacts that we see as being the most probable. Our recommendations in the concluding section are based on these opinions.

Robots and automation. Robots represent the latest development in automation. Automation began with the use of steam power in the late 1700s. Since then, industrialized countries have steadily learned how to make more and more goods with less and less direct human labor. According to data from the U.S. Bureau of Labor Statistics, manufacturing in the United States now accounts for only 25 percent of total employment, compared with 33 percent twenty years ago. Everyone who has lived through this era has seen the impact of this change -- pockets of severe unemployment in the traditional industrial cities. We believe that the use of robots will accelerate this trend, and we agree with the forecasts given in Tables 8 and 9, which are taken from an extensive study by the Upjohn Institute for Employment Research.

Assuming the worst case from these tables, we have a maximum of 200,000 jobs displaced and 32,000 created. Assuming further that half the 200,000 displaced are laid off or terminated, we have a net loss of 68,000 jobs by 1990. In a workforce of 100 million, this is not serious -- unless you are one of those who loses a job.

There's the rub. The job created by robotics, such as a robot systems technician position, is not usually filled by the person displaced or laid off. And though we may talk much about retraining, the fact is that the

Table 8. Predicted Job Displacement in the United States due to Robotics, by Application, Cumulative from 1980 to 1990

Application	1980 Empl. Level	Percentage Displaced (range)	1980 Empl. Level	Percentage Displaced (range)	1980 Empl. Level	Percentage Displaced (range)
Welding	41,159	15-20	359,470	3-6	400,000	4-7
Assembly	175,922	5-10	1,458,228	1-2	1,661,150	1-3
Painting	13,556	27-37	92,622	7-12	106,178	9-15
Machine loading/ unloading	80,725	12-20	988,815	3-7	1,069,540	4-8
All operatives and laborers	467,846	6-11	9,954,048	1-2	10,421,894	1-2

Source: Adapted from Human Resource Implications of Robotics (p. 78) by H. A. Hunt and T. L. Hunt, 1983, Kalamazoo, MI: The W.E. Upjohn Institute for Employment Research.

Table 9. Predicted Direct Job Creation in the United States due to Robotics, by Occupation, 1990

Occupation	Employment Range of Estimate Low	High
Engineers	4,636	9,272
Robotics technicians	12,284	24,568
Other engineering technicans	664	1,328
All other professional and technical workers	936	1,871
Managers, officials, proprietors	1,583	3,166
Sales workers	581	1,162
Clerical workers	2,908	5,817
Skilled craft and related workers	2,163	4,326
Semi-skilled metalworking operatives	2,153	4,306
Assemblers and all other operatives	3,763	7,526
Service workers	138	276
Laborers	279	558
Total	32,008	64,176

Source: From Human Resource Implications of Robotics (p. 139) by H. A. Hunt and T. L. Hunt, 1983, Kalamazoo, MI: The W.E. Upjohn Institute for Employment Research.

laid-off assembler just doesn't have the background or the time to spend two years in electronics school becoming a robot systems technician. More about that later.

The displaced or laid-off worker will probably be a semiskilled metal-working machine operator: a press operator, diecast operator, spot welder, etc. Each company will probably attempt to place such a person in another job in the plant. But in general, metal-working plants aren't in growth industries and must strive to produce more for less labor. Furthermore, the semiskilled operator probably has a 9th-grade education and may not be suited to another job.

Another typical displaced worker is the arc welder. This operator is highly skilled and is among the higher paid workers in the plant. But arc welding is an ideal robot application, and one robot can do the work of perhaps three human operators. The company will probably keep one operator and let two go. (Even with a robot, it is necessary to have an experienced arc welding operator around.)

Union involvement in robots. Union leaders understand the factory floor and the never-ending need to automate. Douglas Fraser, former President of the United Auto Workers, says:

> Our union never opposed the introduction of new technology and automation. That's why we were able to negotiate high wages and rich benefits -- because we're a very, very productive work force. Productivity increases in the auto industry far surpassed the national average. You don't want to resist new technology because it creates the larger economic pie. You're going to have to accept new technology to keep pace with the Japanese. What the unions have to do is make certain that new technology is introduced in a civil way so that workers will not be thrown out in the street. (U.S.A. Today, May 11, 1984)

The problem with Mr. Fraser's statement is that he mentions only the Japanese, whose wages are now about 75 percent of U.S. wages and are rising much faster than those in the United States. But what about Korea, China, and Taiwan? How will we compete against automated factories in those countries, if the few factory workers average $1.50 an hour? This is a larger question than robotics, but it is related and makes the impact of robots pale by comparison.

In summary, the unions will accommodate robots in the way they have accommodated automation in the past: by taking a realistic view of what needs to be automated; by accepting the fact that less senior union members will be displaced; and by negotiating contracts which provide training, severance pay, and job search assistance for those who are displaced. Union membership in the traditional industries will decline, as indeed it already has.

The bright side of employment. As we said earlier, robots are not going to eliminate all factory jobs, at least not by 1990. As evidence of this, we cite the employment statistics of the U.S.'s three newest and most automated automobile plants.

- Nissan (Smyrna, Tennessee): 220 robots, 2,000 employees.
- General Motors (Pontiac, Michigan): 157 robots, 5,500 employees at peak production.
- General Motors (St. Louis, Missouri): approximately 150 robots, 5,000 employees.

Despite the robots and lasers, the paint finishes at the GM plants will, according to a GM employee, still be swabbed by hand with ostrich feathers for smoothness!

ROBOTS AND TRAINING

Educators, particularly at two-year colleges, have made investments of time and money to provide robotics training for their students. According to the Society of Manufacturing Engineers' 1984-1985 issue of its <u>Directory of Robotics Education and Training Institutions</u>, 297 colleges, universities, and technical institutes now have programs in robotics or closely related fields such as automated manufacturing. Seven of these programs offer doctoral degrees; 46, master's degrees; 71, bachelor's degrees; 183, associate degrees; and 29, no degrees. Of the 297 schools, 242 have robot labs.

Assuming that each of the 307 degree programs awards 20 degrees annually, we will have approximately 38,000 professionals with degrees in robotics by 1990. Admittedly, this is a rough calculation, but it appears we may have a robotics professional for every robot installed!

Why is this? . . . Why are there so many programs when there is an average of fewer than 200 robots in use per state, and most of these are in the automotive industry? There are several reasons -- e.g., for about $5,000, a school can buy an educational robot that offers real value to the students -- but the biggest reason is the romance surrounding robots. They are a popular topic. Besides, they are fun! As one professor told us, "I can't keep the students out of the robot lab. Students who formerly cut the labs now stay overtime!"

In Michigan and the other automobile-manufacturing states, there have been more urgent reasons for robotics education programs: the jobs are right there. McComb Community College in Warren, Michigan, responding to the auto companies' demand, became one of the early leaders in robot

education. As McComb graduates were hired, other schools (such as Oakland under the direction of Ed Knoppa, formerly of McComb) opened comprehensive technology centers, including training in robotics.

Another practical approach was taken by schools such as Chattanooga State Technical Community College. Chattanooga has a broad industrial base, primarily in metal-working and textiles. In 1980, 42 percent of the population were employed in manufacturing jobs. Chattanooga State felt that it was important for local industry to have a source of trained technical personnel. Programs in robots, along with computer-aided design (CAD) and computer numerical control (CNC) were established to help traditional local companies take advantage of the newest technology.

Elsewhere in the South -- in the Carolinas, Florida, and Mississippi -- there are similar programs with similar motives. These robotics education programs have been established and funded to promote economic development, on the theory that companies will build manufacturing plants where technical education is available.

Danger Signals for Two-Year Colleges

We are concerned that many two-year colleges are offering narrow associate degrees in robotics when very few jobs will be available for their graduates. Only the largest companies will have enough robots to consider hiring someone whose specialty is limited to robot technician work. In fact, a high-ranking official at General Electric, one of the largest robot users, told the authors that he would not even interview someone with such a narrow specialty. Nissan Motors in Tennessee, with

over 200 robots installed in one plant, does not have a job slot for a technician who specializes solely in robots.

We believe that two-year-college students are best served by a broad education in either electronic or mechanical theory, with robot application courses as part of their second-year studies. They should know the theory and practice of robots, but, even if they never see a robot after college, they should be able to find jobs.

From its inception, Chattanooga State's robotics program has been part of a broad course of study on automation systems. This course of study involves a thorough education in basic electronic theory followed by application studies, including robotics, programmable controllers, computer-controlled machine tools, and computer-aided design. A graduate should know basic electronic theory and should be able to design, install, and maintain all the communication links necessary to form a manufacturing system, even if no robots are involved.

Four-Year Robotics Education

The authors have had no experience organizing robotics education at the four-year-college level, but they have visited several universities that are involved in robotics. Carnegie Mellon in Pittsburgh has a very broad robotics research program. Brigham Young in Provo, Utah has an excellent manufacturing engineering program which includes robots. Purdue University is installing a total system of manufacturing automation. Georgia Tech is specializing in automated material handling. The Massachusetts Institute of Technology, the University of Michigan, and the

University of Florida have well-established robotics research programs. For a complete listing of all colleges and universities offering robotics training, contact the Society of Manufacturing Engineers in Dearborn, Michigan. As noted previously, they publish an annual directory of schools offering robotics training.

Recommendations for Robotics Education

The recommendations below are based on the authors' experience in robotics education at the two-year technical-college level, plus visits to many educational institutions at all levels.

Secondary vocational schools. Secondary vocational schools should not offer robotics training. Instead, they should offer the basics in electronic and mechanical subjects. These basics can then be the foundation for specific robotics training in industry or in a technical college.

Specific robotics training at the secondary level is unlikely to lead to robot-related jobs in industry unless a particular local company has sponsored a training program and offered jobs to the graduates. Nor will specific robot training at the secondary level prepare a student for the academic requirements of a technical college. The theory — of computers, mechanics, and electronics — must precede specific robotics training.

Two-year technical colleges with robotics programs. The greatest number of robotics training courses are being offered in two-year technical colleges. At the last count, 183 colleges offered associate degrees in robotics -- 123 of them with robot labs (Society of Manufacturing

Engineers, 1984-1985). In addition to the recommendations below, these colleges might wish to consult the list which follows, to obtain suggestions about possible program revisions.

1. Don't call your program "Robotics" unless you are being sponsored by a robot user who will hire your graduates. Call it something like "Automation Systems" or "Advanced Manufacturing Systems." Robotics is too narrow a specialty.

2. Tell your incoming freshmen that they should not plan on jobs involving only the use of robots. Educators with industrial contacts have known this all along. But an 18- or 19-year-old freshman accepts at full value the "robot revolution" stories which circulate through the media.

3. Add the use of programmable controllers as part of the robotics training. A graduate who understands programmable controllers will be valuable to all sorts of industrial companies, even if the company never uses a robot.

4. Send a personalized letter to every company selling robots. Ask for video tapes of their products plus any case studies they have on applications of their robots. We have found these to be very valuable.

5. Join the Robotics International Division of the Society of Manufacturing Engineers. They have excellent educational materials.

6. Offer to establish a summer program for high school and college teachers in your state. Assuming you are a state-supported school, your state governing boards should help finance and organize such a program.

7. Invite your state's department of economic development to come for a one-day seminar. It is a source of support, financial and otherwise.

Two-year colleges with no robotics programs. The following recommendations might be considered before starting or revising a robotics program.

1. By surveying local industry, find out whether a robotics program is needed in your area. A needs assessment is the normal way for two-year technical colleges to determine what to offer, yet robotics programs have occasionally (perhaps usually) been started without needs assessments. Many educators with whom we have talked feel that their schools will fall behind without robotics programs.

2. Assuming that a robotics program is needed in your area, what should you teach? Should the program stand alone or be an option within an existing course of study? Should the program focus on electronics or mechanics? Should it focus on theory or application? What are the industrial jobs for which your graduates will apply? This last question is a key one, since you need to know what your graduates should be able to do. If this question is pursued vigorously with local industry, it will answer many of the other questions.

3. No one set of recommendations can apply to every two-year college. The local area's needs will determine how involved with robotics the college should become. We see four distinct levels. These are listed below in ascending order of complexity and funding.

- Level 1: a program using video tapes and printed material to show the theory and application of robots. This program would not be listed in the catalog but would simply be added to an existing course.

- Level 2: all items in Level 1 plus hands-on experience with educational robots. (See Appendix A for a list of sources of

such robots.) These robots cost from $1,500 to $5,000 and come with instructors' guides and lab exercises. Our experience indicates that students learn as much (or more) about the theory of robots from these machines as from full-size ones. But they can't learn applications.

- Level 3: all of Level 1 and Level 2 plus a full-size robot in an application cell. If a college is going to acquire only one robot, we recommend an electric, 5- or 6-axis, jointed-arm robot. With such a robot, costing $40,000-$50,000, virtually every kind of application can be taught. This type of robot was originally designed for arc welding but has been used for nearly every kind of application except spray painting. They are rugged machines requiring practically no mechanical maintenance -- which is one reason why we see no sense in training people to specialize in robot maintenance. With Level 3, you'll need an electronics technician to interface the robot with peripheral devices.

- Level 4: all of Levels 1, 2, and 3 plus a variety of robots performing a variety of tasks in conjunction with other computer-controlled equipment, programmable controllers, and perhaps a CAD system. This is currently the ultimate in a computer-integrated manufacturing system, with a cost running into seven figures. The National Bureau of Standards in Washington, DC has such a system. Its value for educational purposes is that all of the elements of an advanced manufacturing system can be seen in one location. From a practical standpoint, we recommend that there be one such installation in each industrial state, and that instructors from more modest robotics programs be trained there in summer workshops. Students and company employees desiring sophisticated hands-on training could also attend the summer workshops or special courses designed to meet their needs.

4. Regardless of the level of robotics training chosen, we recommend that students be taught to integrate robots into <u>systems</u> of production machinery. We believe that industry's greatest need from a two-year college is for students who have the electronics and computer knowledge to interface the newest production equipment, including robots. We have found that students trained in electronics can pick up a lot of the mechanical elements of robotics on the job, but students trained in mechanics cannot similarly pick up electronic elements. For this reason, at Chattanooga

State, the robotics program is an option of the electronics technology program.

5. A robotics education program should include at least $3,000 annually per instructor to cover the cost of courses for the instructor, plus travel expenses. Robotics is a fast-changing field. Your instructors will never finish their own learning processes.

Industrial managers. These recommendations are based on one author's experience in appliance manufacturing prior to becoming an educator.

1. Even if your production volume is low, consider robotics. Single pneumatic robots costing between $10,000 and $20,000 can replace a machine loader on every shift. Some robot applications can pay for themselves in less than nine months.

2. If you feel inadequate in robotics, ask your local technical school for help. They are looking for real-life applications.

3. While robots are simply production machines, they may represent threats to your employees' jobs. For your first robot application, pick an unpleasant job — a job that nobody really likes.

4. Involve production employees in the robot feasibility study. If they understand the robot application, they will make it work. If they don't want it to succeed, you'll have continual problems and will probably never install a second robot.

5. If possible, install the first robot during a period of business expansion so that you don't lay anyone off. Employees cannot be expected to support automation when their jobs are threatened.

6. Don't order a robot by itself, figuring your own staff will make

it work. Buy a turnkey production cell. Most robot manufacturers offer this service or will refer you to the robot systems firm they use to design the cells. Specify the job or jobs the robot is supposed to do, and only pay the vendor when the robot is performing them satisfactorily. If a vendor will not agree to this arrangement, change vendors.

Government manpower agencies. These recommendations are based on the authors' experience with the local Private Industry Council in Chattanooga.

1. Don't be concerned about robots causing large-scale unemployment. Robots will be only one of many factors which will cause a drop in the percentage of Americans working on the factory floor.

2. Don't attempt to set up short-term robotics training unless a specific company is offering jobs at the completion of training. The demand for robotics people is simply not great enough to justify spending government funds on robotics training.

3. Do be concerned about entire plants being closed, relocated hundreds of miles away, and rebuilt with completely automated production systems. Some industrial managers believe that it is more effective to design an entirely new plant than to automate an old one piecemeal. This type of decision goes far beyond robots. It may not affect aggregate national employment figures, but it can cause severe local problems.

4. Don't bet too heavily on the bright promise of "high-tech retraining" for displaced workers who have been laid off or discharged. If jobs are available locally in some field akin to the worker's former job, then retraining has real possibilities. The training can be short-term, and many of the skills may be transferable from the old job to the new.

one. But if the person has been in a well-paid but unskilled job (the type most likely to be displaced by a robot), one to two years of training will be needed to learn a new, marketable skill paying comparable wages. How many unskilled workers have the basic educational background to handle training in the new technologies of computers, electronics, and robotics? -- And even if they do, how many have the money to stop work and pursue expensive training? These are some of the obstacles to high-tech retraining.

5. Accept the fact that many displaced industrial workers can best be trained to handle local service jobs. These jobs don't usually pay as much as an industrial job, but they are available, their required knowledge can be learned in short-term government-sponsored training programs, and they are usually non-cyclical. Examples abound in food service, route sales, store clerking, and similar areas. Because of personnel turnover, these jobs frequently offer opportunities for at least one- or two-stage advancement. Convenience store clerks frequently become store managers.

Students at two-year technical colleges.

1. Don't count on a knowledge of robots to get you a job unless a company using robots has discussed hiring you. There just aren't enough robots around.

2. Achieve a basic understanding of electronics and computers. These are at the heart of all robot applications and will enable you to get a job even if you never see another robot.

3. If possible, become proficient at either robotic arc-welding, robotic electronic-parts assembly, robot machine-loading, or all three.

Then, when applying for a job, find out what robot applications the company has. Chances are the company will be using one of these three applications and will be interested in you if you are good at what they are doing.

CONCLUSION

As discussed earlier in the paper, all of the technical constraints of robotics are being vigorously attacked by several major American manufacturing companies; among them General Motors, General Electric, Westinghouse, and Cincinnati-Milacron. In five to ten years, we should see significant improvements in the technical capabilities of robots. In addition, the U.S. Congress is considering several bills which would offer incentives for companies to invest in robots. (These bills have not been analyzed here, because they are beyond this paper's scope.) If the industrial economy continues to look prosperous, we may see more robots installed than have been forecasted here; if the economy stalls, we may see less.

In education, we are producing an annual crop of graduates in robotics who are eager to find jobs and apply their new knowledge. But, as the prior section has cautioned, it is important to keep educational services in balance with industry needs. In some instances, it is necessary to lead industry by offering training in a field before industry perceives a need for people so trained. This can help to stimulate industry's interest in the field, but the people trained may not be able to find jobs immediately in their particular areas of expertise. Robotics may be a case in point.

APPENDIX A

Educational and Hobby Robot Systems

RB Robot Corporation 18301 West 10th Avenue Suite 310 Golden, CO 80401	RB5X (mobile)
TII, Inc. 401 North Salem Avenue Arlington Heights, IL 60005	BRAT Series (fixed)
TecQuipment, Inc. P.O. Box 1074 Action, MA 01720 (617) 263-1767	TQ Smart Arms (fixed)
Q&M Computing, Inc. P.O. Box 2102 Fargo, ND 58107 (701) 235-7743	Armdroid I (fixed)
Microbot, Inc. 453-H Ravendale Drive Mountain View, CA 94043 (415) 988-8911	Minimover (all fixed) Teachmover, Alpha
Amatrol, Inc. P.O. Box 2097 Clarksville, IN 47130 (812) 288-8285	Polaris (all fixed) Centari, Mercury, Hercules
Iowa Precision Robotics, Ltd. 908 10th Street Milford, IA 51351 (712) 338-2047	Marvin (mobile)
Executive Management Company 2425 East Thomas Road Suite 8 Phoenix, AZ 85016	ComroTot (mobile)
Harvard Associates, Inc. 260 Beacon Street Somerville, MA 02143 (617) 492-0660	Turtle Tot (mobile)
Technovate, Inc. 910 SW 12th Avenue Pompano Beach, FL 33060 (305) 946-4470	Model 5440 (fixed) (IBM 7535 with complete work cell)

Educational and Hobby Robot Systems (Continued)

Feedback, Inc. 620 Springfield Avenue Berkeley Heights, NJ 07922 (201) 464-5181	Armdraulic (both fixed and mobile) Armover, Armadilla, others
Prep, Inc. 1007 Whitehead Road Ext. Trenton, NJ 08638 (609) 882-2668	Scorbot (fixed)
Hobby Robot Company P.O. Box 887 Hazelhurst, GA 31539 (912) 375-7821	Rabbit (mobile)
Lab-Volt Systems P.O. Box 686 Farmingdale, NJ 07727 (201) 938-2000	

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HIGH TECHNOLOGY EDUCATION: A PROGRAM OF WORK

The following publications have been developed by the Office for Research in High Technology Education for the U.S. Department of Education's Office of Vocational and Adult Education:

At Home in the Office:

- At Home in the Office: A Guide for the Home Worker

COMTASK:

- Procedures for Conducting a Job Analysis: A Manual for the COMTASK Database
- COMTASK User's Guide

State-of-the-Art Papers:

- The Changing Business Environment: Implications for Vocational Curricula
- Computer Literacy in Vocational Education: Perspectives and Directions
- Computer Software for Vocational Education: Development and Evaluation
- Educating for the Future: The Effects of Some Recent Legislation on Secondary Vocational Education
- The Electronic Cottage
- High Technology in Rural Settings
- (Re)Training Adults for New Office and Business Technologies
- Robots, Jobs, and Education
- Work in a World of High Technology: Problems and Prospects for Disadvantaged Workers